Performance simulation of a MRPC-based PET Imaging System

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Plan of the presentation:

- Introduction to Positron Emission Tomography(PET)
- Simulation and Results
- Construction of a six-gap glass based MRPC
- Test results using a ^{22}Na source
- Summary and Outlook

What is PET Imaging ?

A powerful and sensitive technique for functional imaging in the field of Nuclear Medicine. It is a radiotracer imaging technique in which radiopharmaceuticals labelled with positron emitting radionuclides are injected into the patient. The tracers can be used to track biomedical and physiological processes.

- Basic Principle :

A positron emitting radiopharmaceutical injection into the patient → annihilation with electrons in the tissue producing two back-to-back 511keV photons → measurement in electronic coincidence by using opposing pairs of detectors

In TOF-PET, by measuring the time difference between the two detected photons we can get the annihilation position along the line of response

Sensitivity is a fundamental parameter of PET systems. It determines :

the amount of radioactive tracer to be administered to the patient
the observation time
the noise level in the image for a given image granularity.

Any improvement in system sensitivity will allow a corresponding improvement in one of these parameters or in a combination of them.

MRPC in TOF-PET imaging:

TOF-PET imaging requirements:

1. good time resolution (~100 ps or less)
2. position resolution (~ mm)
3. high efficiency of the detector (~ 90 – 100%)

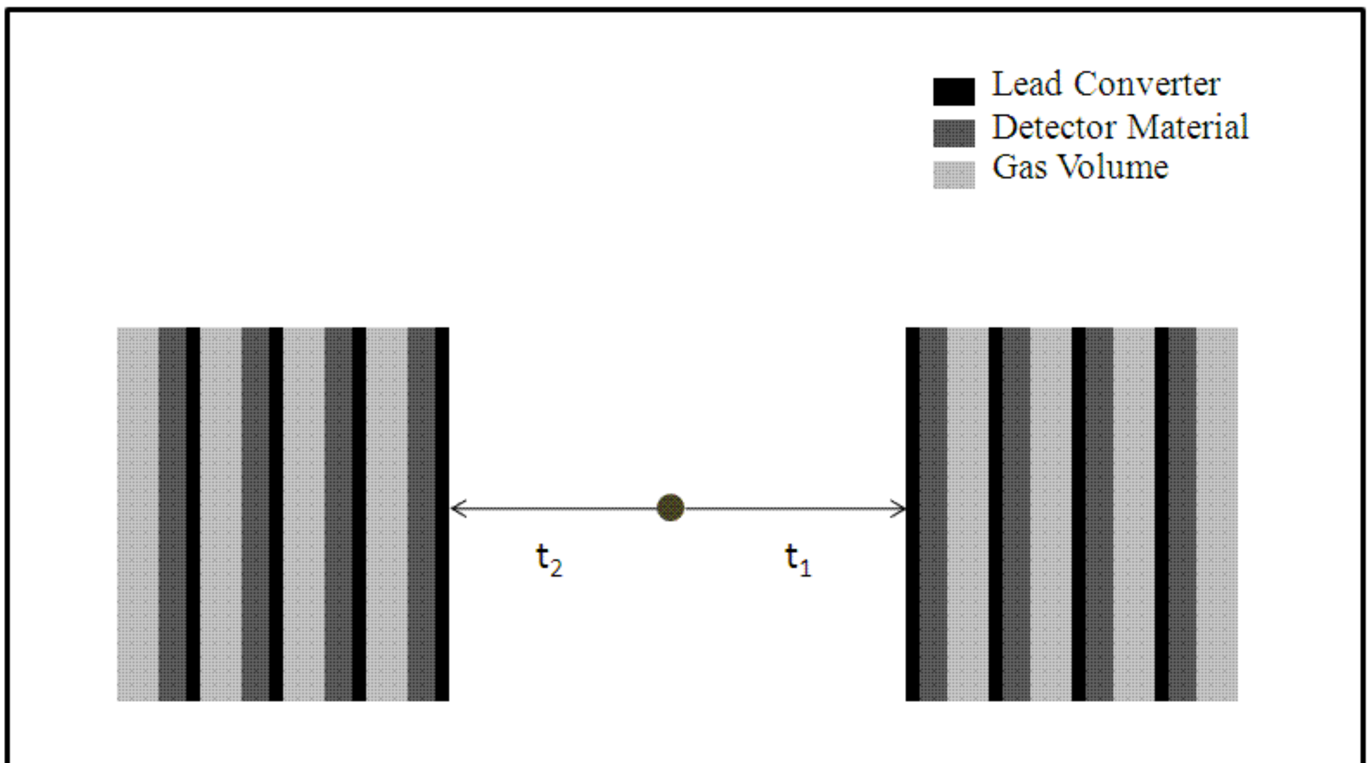
MRPC satisfies all the above properties

Less expensive
Large Field-of-View
Modular to suit the efficiency requirement

Simulation for present study is performed in two stages

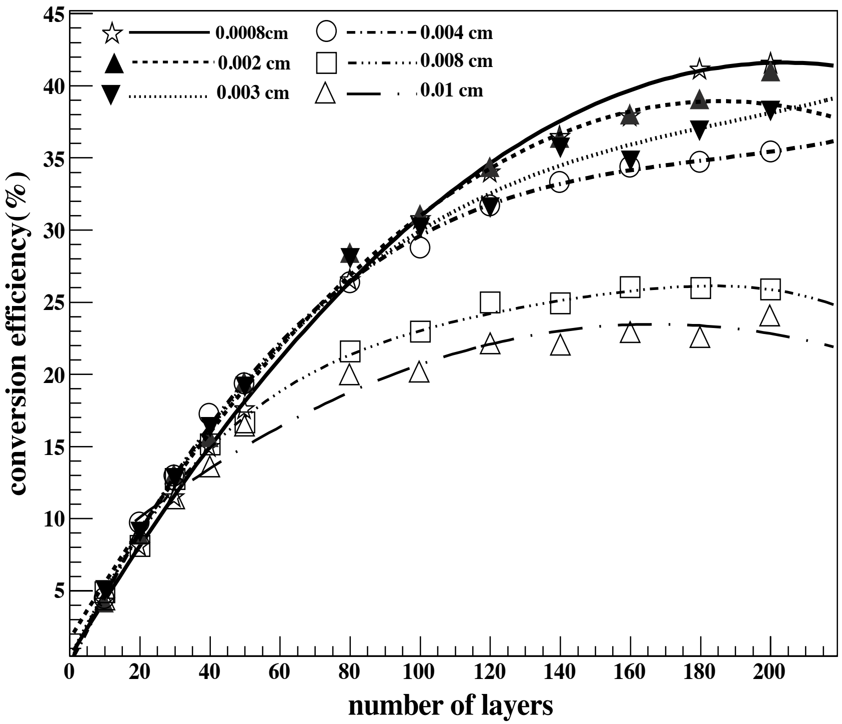
i) Study of conversion efficiency and the optimization of the converter nature and thickness

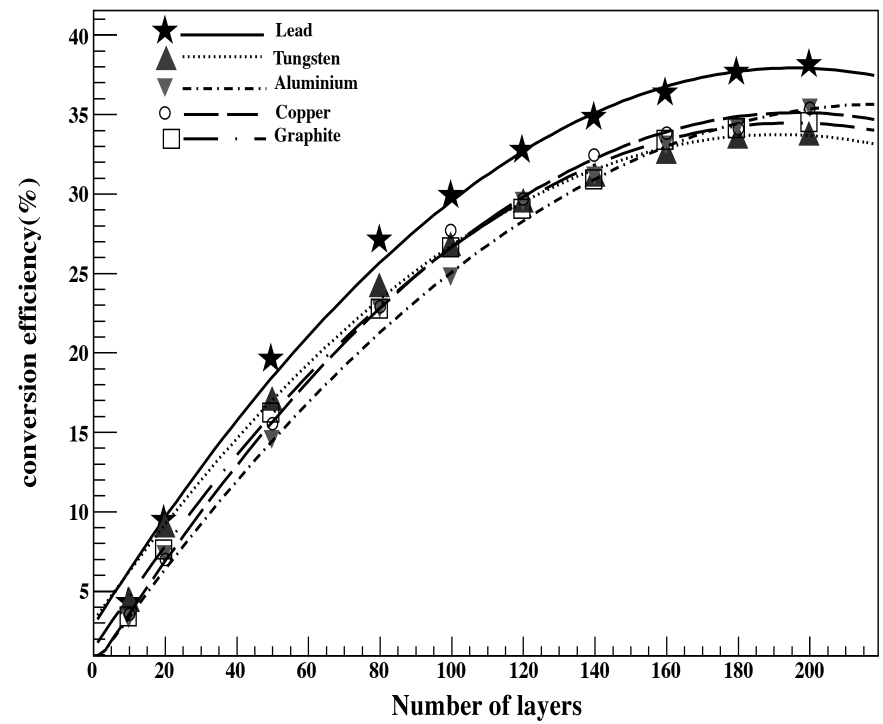
ii) Study of measurement of timing response of MRPC.



Simulation Results :

Conversion Efficiency





Optimum Results :

Lead as the converter material
No. of layers greater than 100
Lead foil thickness of about 40 μm

• Steps of Simulation :

- Total gap (d mm) is divided into n number of sub-gaps. So,
  $\Delta x = d/n$ (mm)
  corresponding to the time
  $\Delta t = \Delta x/v$ (μsec), v = drift velocity (μm/ns)

- In each step primary ionization and the avalanche process is simulated

- Avalanche development probability is governed by

$$P(n,x) = \begin{cases} k\dfrac{\bar{n}(x)-1}{\bar{n}(x)-k}, & n = 0 \\ \bar{n}(x)\left(\dfrac{1-k}{\bar{n}(x)-k}\right)^2\left(\dfrac{\bar{n}(x)-1}{\bar{n}(x)-k}\right)^2 & n > 0 \end{cases} \qquad where\ \bar{n}(x) = e^{(\alpha-\eta)x}, \quad k = \frac{\eta}{\alpha}$$

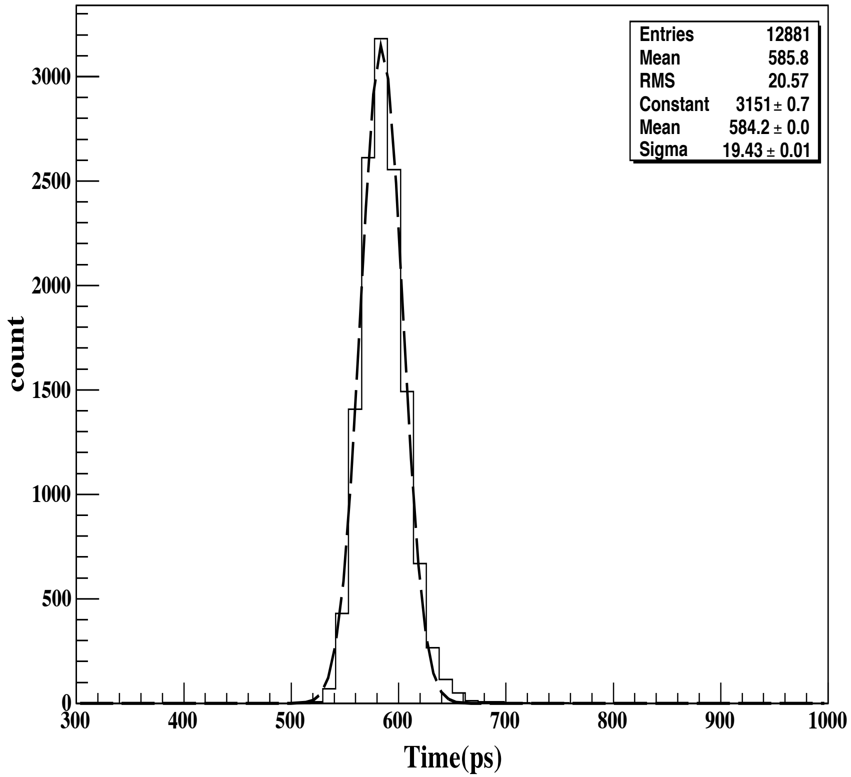
  α and η are the Townsend and the Attachment coefficients respectively

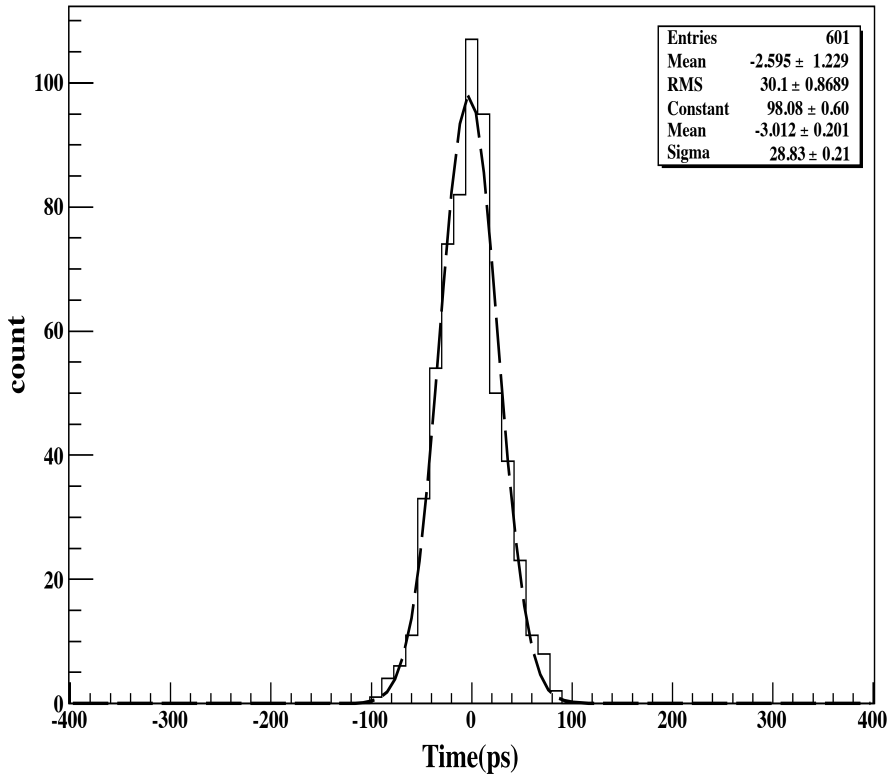
- For each incident particle current and induced charge is simulated from the following formulae:

  $i(t) = (Ew/Vw)\ v\ e_0\ N(t)$ (μAmp)
  $q(t) = i(t)\ .\ \Delta t$ (pC)

- Timing response of the detector is also simulated by introducing a charge threshold (20 fC in our case).
- In this simulation space charge effect is also considered.

•Ref: Detector physics and simulation of RPC ,Werner Riegler *et al.* , NIM A 500 (2003) 144.





Time resolution of the detector **Pair Time resolution**

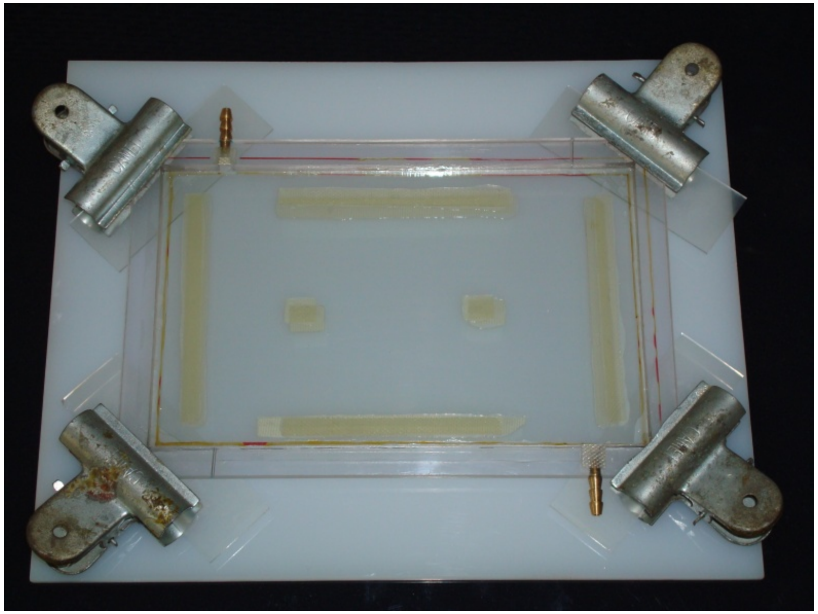
- Time resolution (σ) of the detector for a single photon = 19.43 ps
- Pair time resolution for a pair of photons = 28.83 ps
- **Pair time resolution ~ √2 * Time resolution of a single detector**

Fabrication and testing of a six gap glass-based MRPC

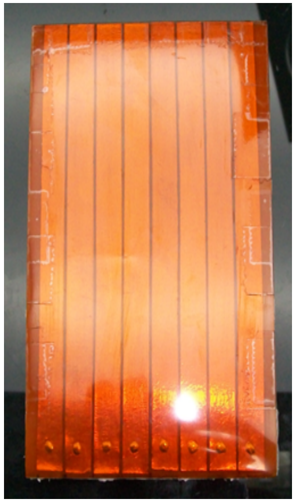
- One six-gap MRPC has been built and tested in the avalanche mode with a gas mixture of Freon(R-134a)/ iso-butane = 95/5 and tested with ^{22}Na source.
- Detector has been made by 600 μm glass obtained from GSI, Germany
- Detector dimension: 16 cm x 10 cm
- No. of gaps: 6
- Each gap width: 200 μm

Six Gap Glass MRPC :

Dimension : 16 cm X 10 cm



- Glass: procured from GSI
- Glass Thickness : 600 μm
- Gas gap: 200 μm
- Graphite paint is used as conductive material



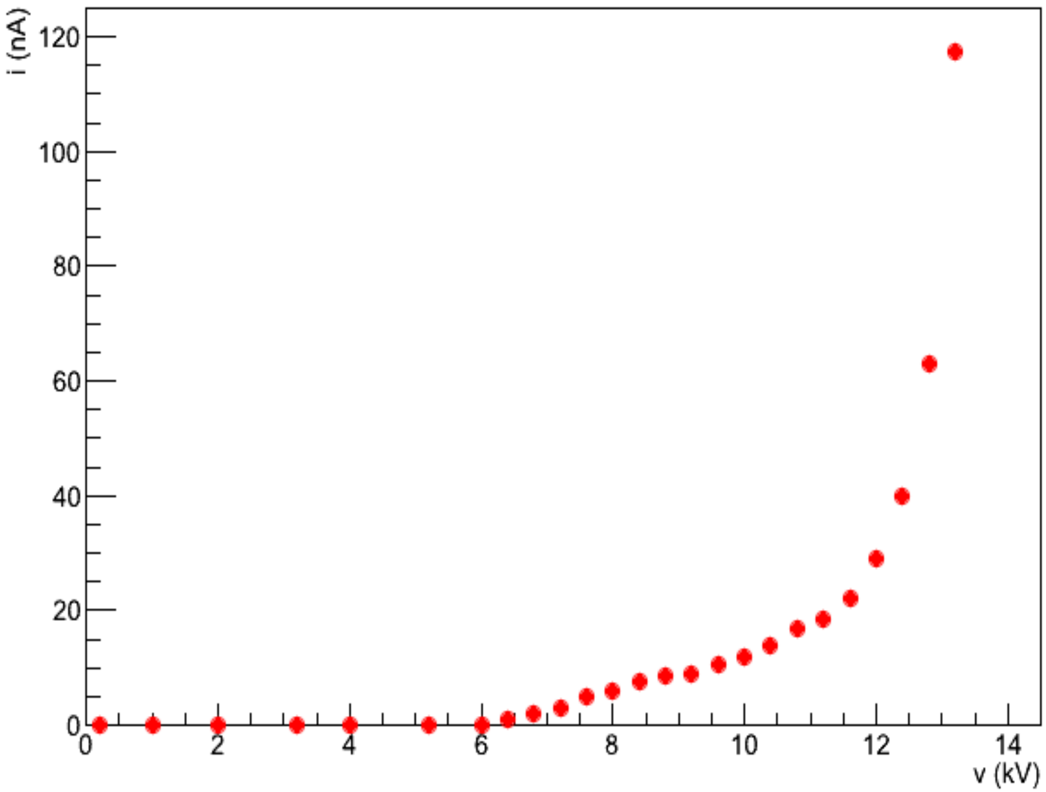
A. Banerjee et al., Nucl. Instrum. Meth. A 718 (2013) 138.

Trigger Scheme for cosmic ray

Detector	HV	Threshold
Large Scintillator 1 (LS1)	-1700 V	-30 mV
Large Scintillator 2 (LS2)	-1700 V	-30 mV
Finger Scintillator 1 [20 cm x 4 cm] (FS1)	-1200 V	-30 mV
Finger Scintillator 2 [5 cm x 1.2 cm] (FS2)	-1100 V	-30 mV
MRPC		-20 mV

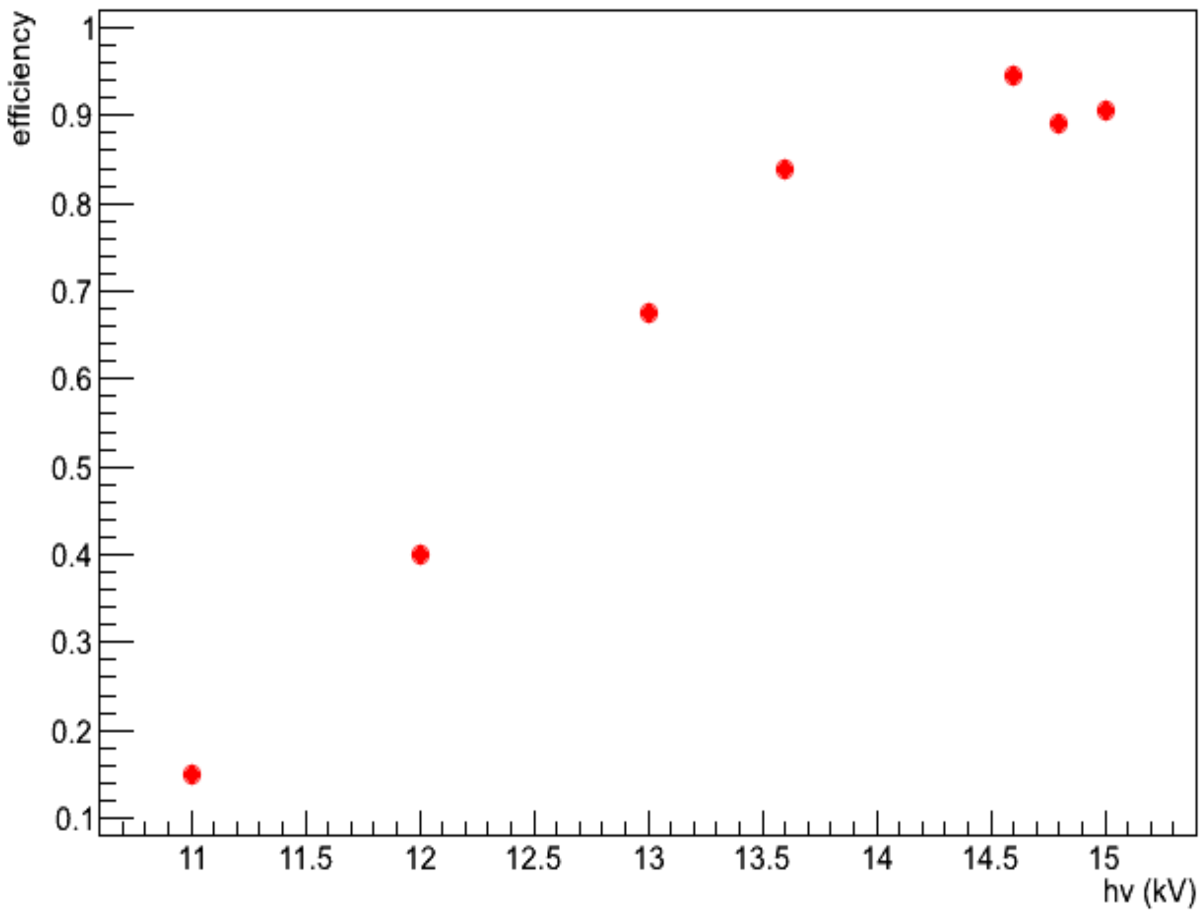
- Trigger (4F) : LS1 x LS2 x FS1 x FS2
- (5F) : LS1 x LS2 x FS1 x FS2 x (Strip 3 OR Strip 4 OR Strip 5 OR Strip 6)
- Efficiency : 5F/4F
- Trigger rate : 4F/(time in sec x 5 cm x 1.2 cm)
- Noise rate : Single strip count /(time in sec x 1 cm x 16 cm)

Cosmic ray Test Results of the Six-gap glass MRPC



•The two slopes in the I-V plot characterize the MRPC response

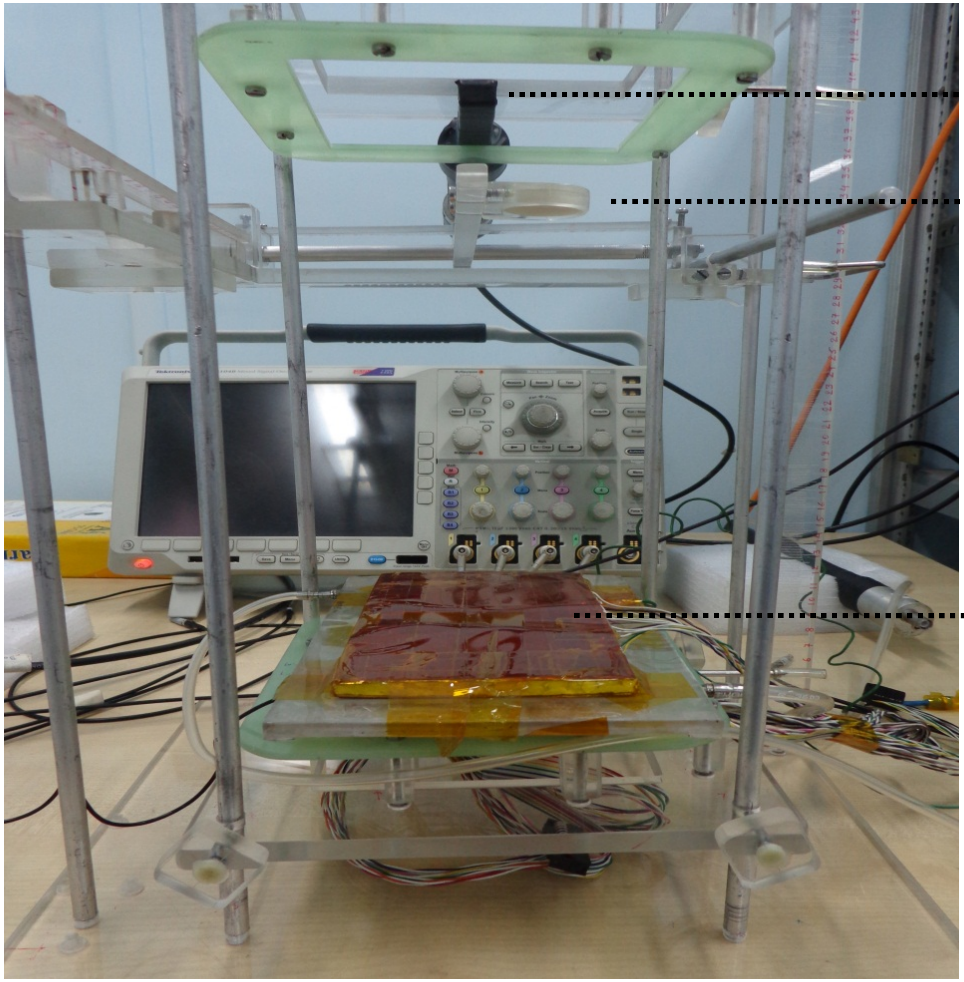
•Bulk resistivity of the glass : ~ $1.68\times 10^{13}\ \Omega$ cm



Cosmic ray detection efficiency is >90% for HV ~15kV

Test results of the Six-gap MRPC with the ^{22}Na source

Experimental setup with ^{22}Na source

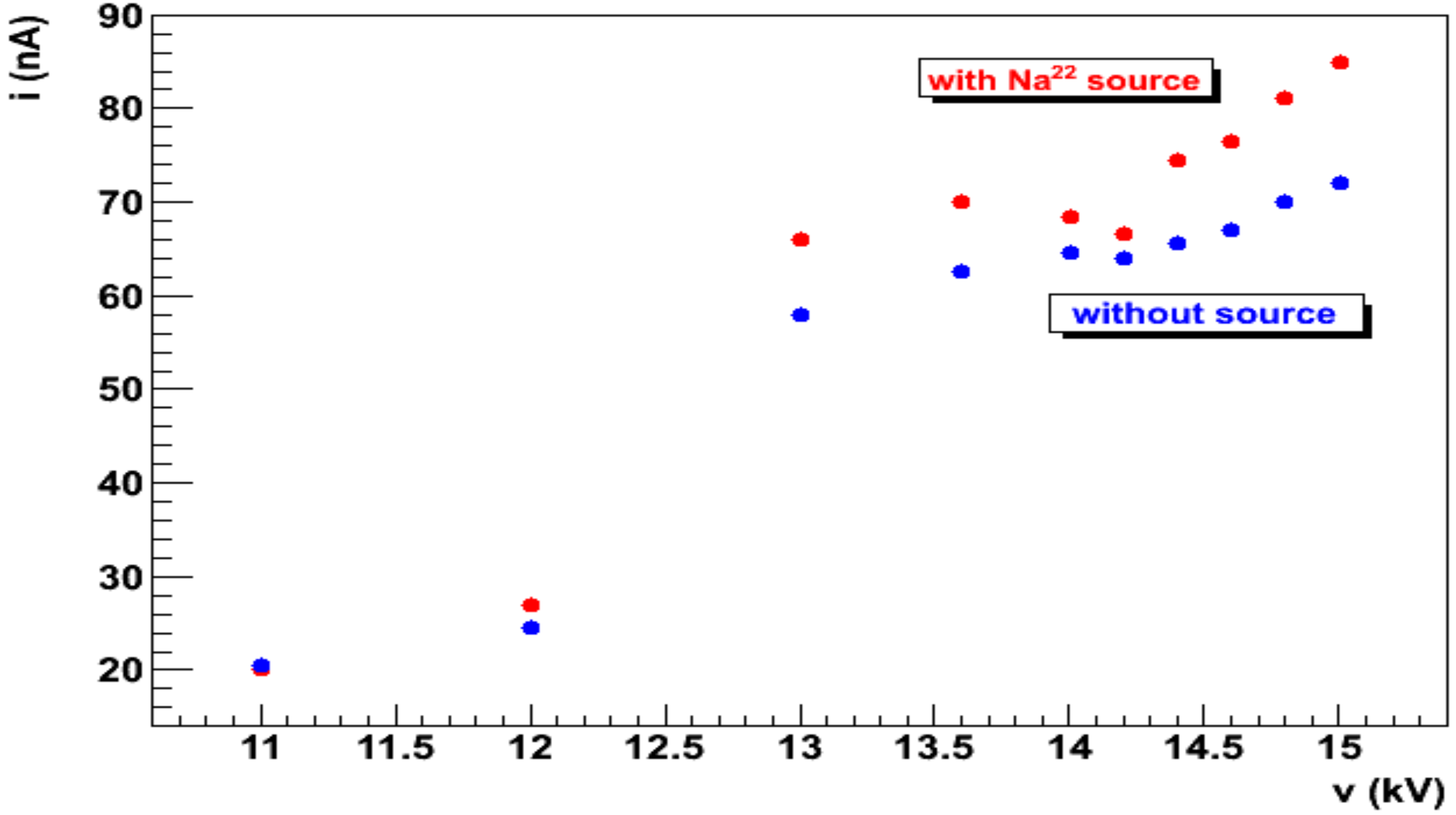


Finger Scintillator

^{22}Na Source

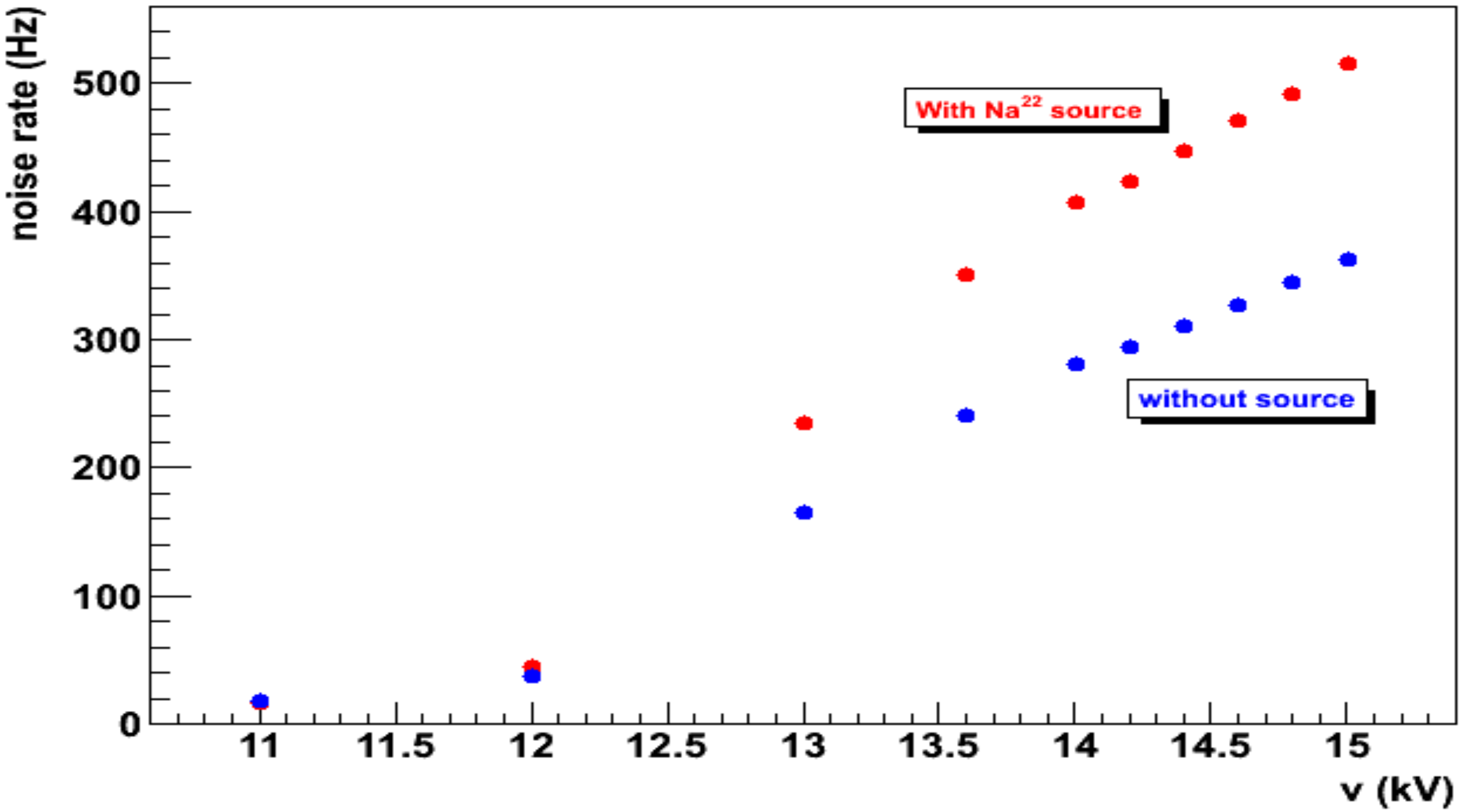
MRPC Detector

I-V Plot



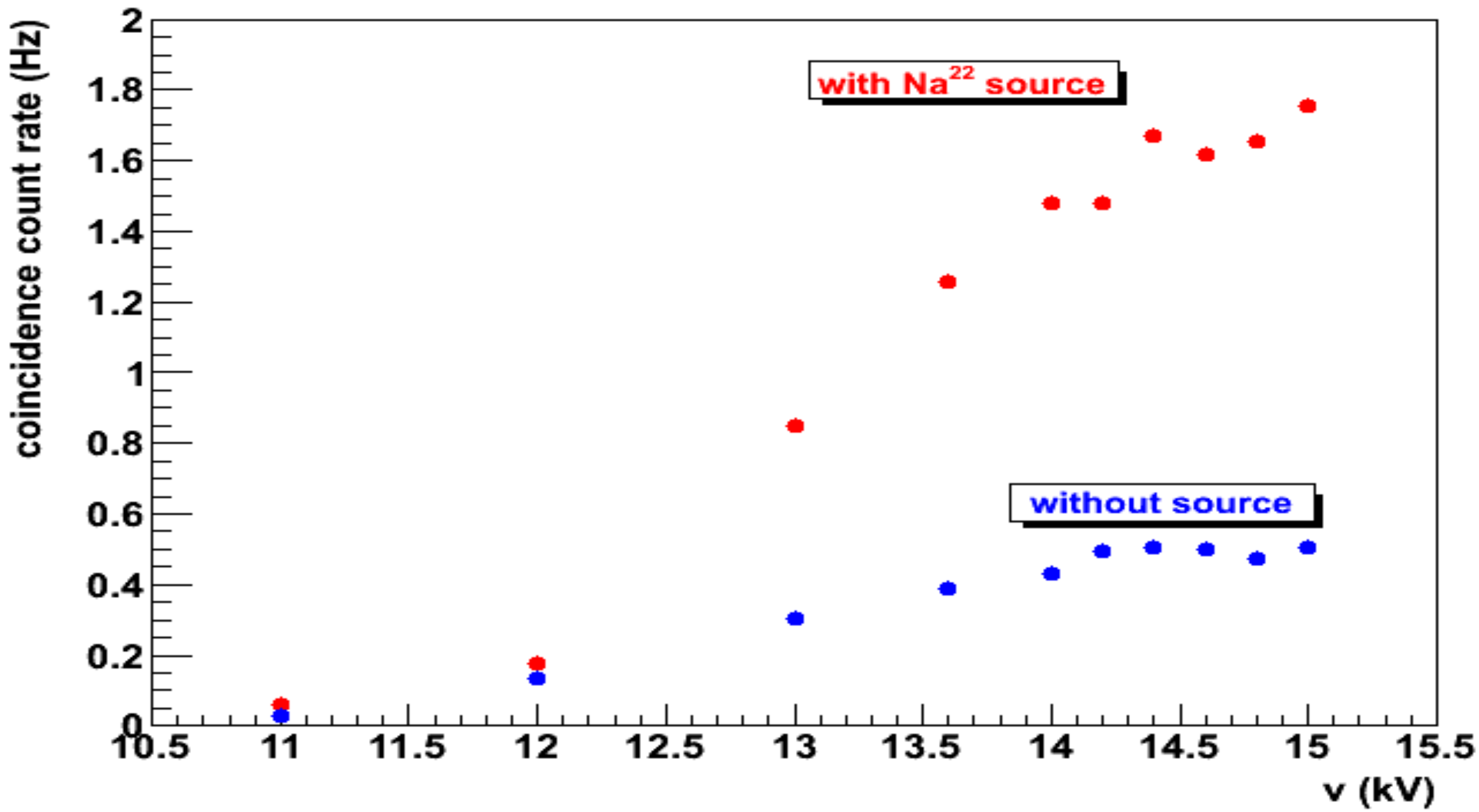
There is a clear difference in the I-V plot with and without the source

Noise rate Vs. high voltage for MRPC



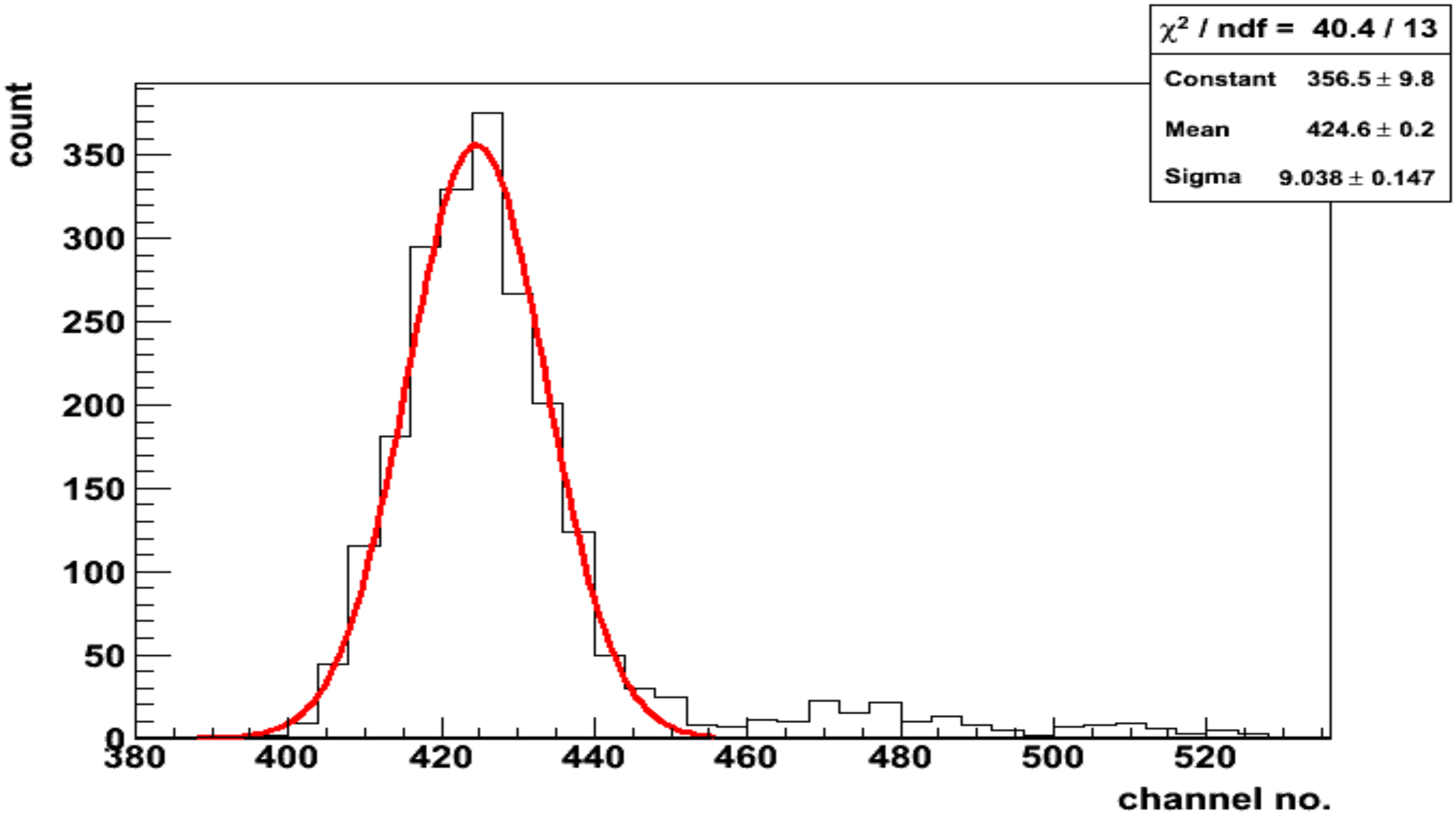
There is a significant increase in the noise rate with the source

Coincidence rate Vs. high voltage



The last 3 slides where we have shown the comparison plots of the behaviour of the detector, with and without the source, emphasize the fact that the source has a major influence

Time spectrum with ^{22}Na source



Time resolution ~ 550 ps

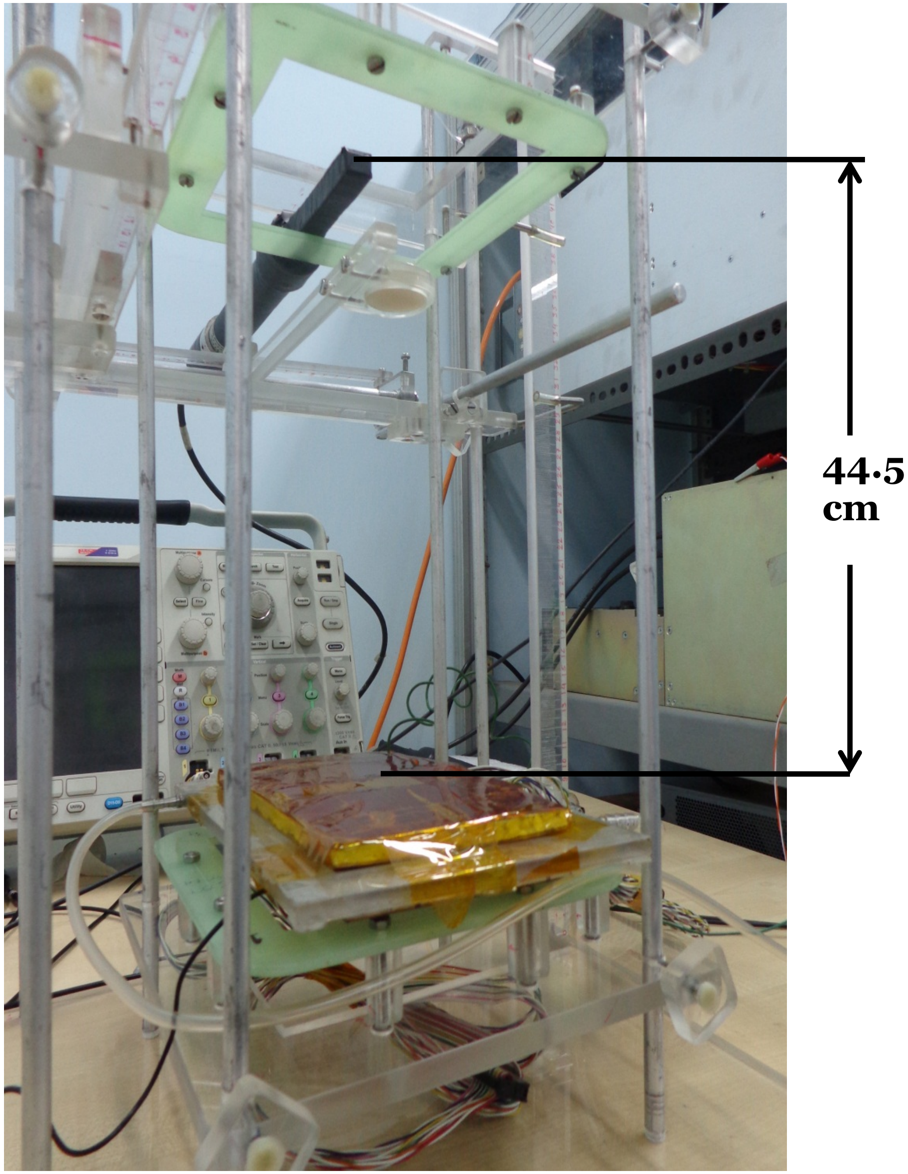
•Distance between Scintillator and the MRPC: 44.5 cm

•Length is measured from the MRPC (As shown in the x axis of the plot in the next slide)

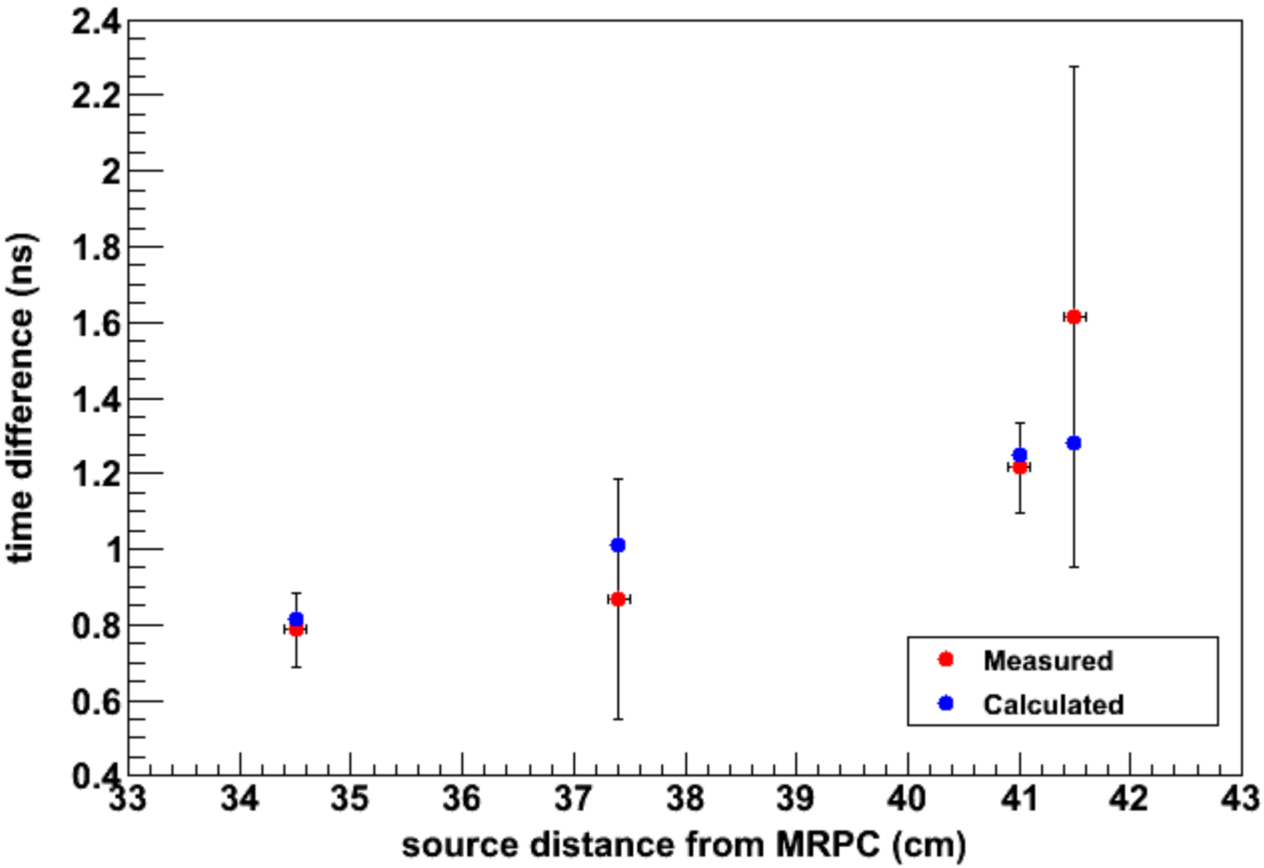
•Calculated time difference
= Stop time - Start time
= (length/30) - ((44.5-length)/30)

•Velocity of gamma is (velocity of light) = 30 cm/ns

•Electronic delay between start and stop signal (during the experiment): 120.3 ns



Variation of time resolution with the distance between source and the detector



- Electronics delay has been subtracted while plotting the variation
- Error bars in the y-axis are statistical errors
- From the plot, it can be said that a position resolution of 0.5 cm can be estimated with the current experimental set-up.

- **Operating voltage = 15 kV**
- **Detector threshold = 20 mV**
- **Time resolution of the detector = 550 ps**

A. Roy et al., 2014 JINST 9 C10030 doi:10.1088/1748-0221/9/10/C10030.

Summary:

1. MRPCs are suitable candidates for PET imaging requiring high time and position resolution.

2. One six-gap glass based MRPC (~600 μm thickness and ~200 μm gap width) was tested.

3. Operation in avalanche mode gives time resolution (σ) ~ 400 ps

4. Gamma detection (511 keV) can be possible with MRPC with the present set-up with an approximate position resolution of 5 mm.

Outlook :

1. Improve the time resolution measurement

2. Testing two five-gap MRPC's with source for more precise time and position resolution

3. Build one full 3-D system with MRPC and test with two gamma (511 keV) for more accurate position resolution

4. More realistic simulation

Acknowledgement :

Subhasis Chattopadhyay, Satyajit Saha, Saikat Biswas, Ganesh Das, Tapasi Ghosh, Jayant Kumar

References:

[1] *R. Santonico, R. Cardarelli, Nucl. Instr. and Meth. 187 (1981) 377.*

[2] *E. Cerron Zeballos, et al., Nucl. Instr. and Meth. A 374 (1996) 132.*

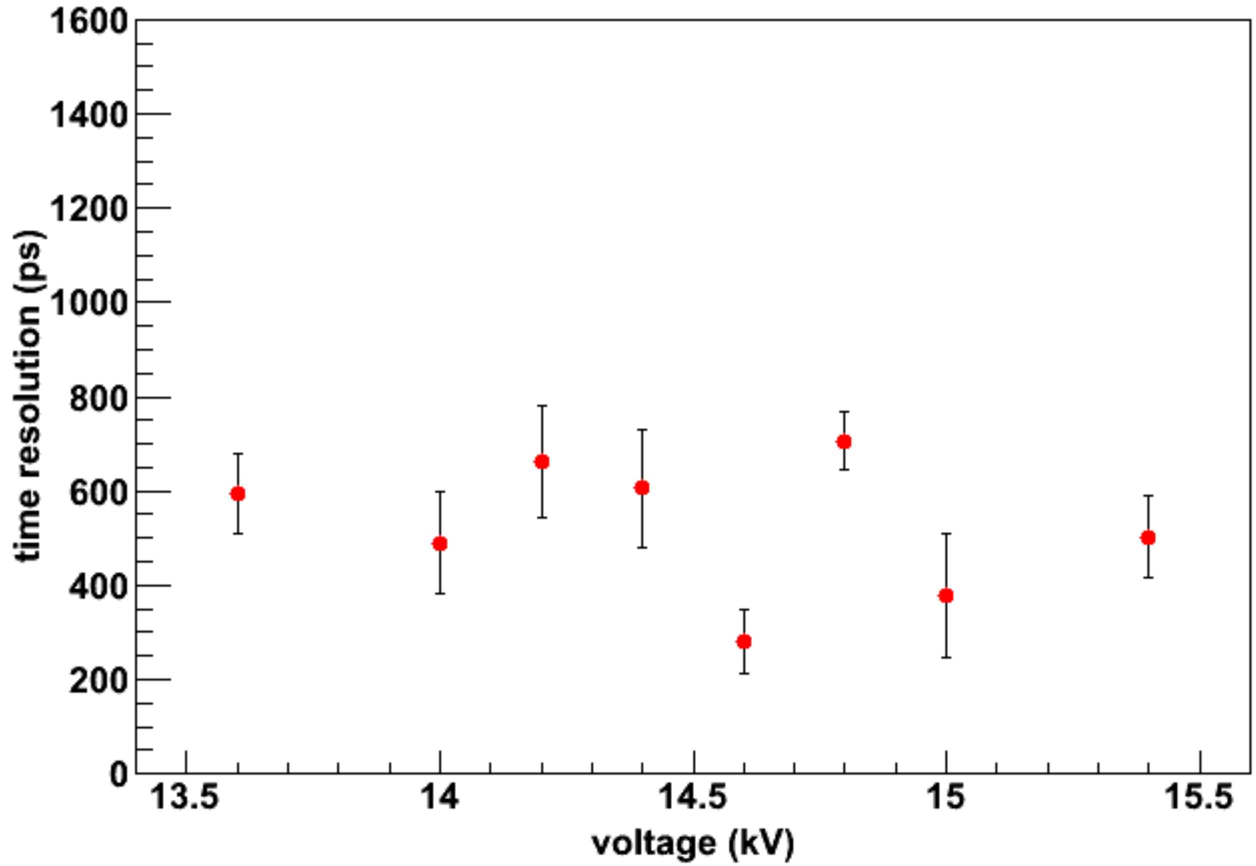
[3] *S. Biswas, et al., Nucl. Instr. and Meth. A 602 (2009) 749.*

[4] *S. Biswas, et al., Nucl. Instr. and Meth. A 604 (2009) 310.*

[5] *Development of multi-gap RPC, A. Banerjee, et al., Proceedings of the International Symposium on Nuclear Physics,Volume 54, (2009), 662.*

Thank you

•Variation of time resolution with voltage



•Time resolution : START with Master trigger

• STOP with MRPC

•At the operating voltage 15 kV time resolution ~ 400 ps